No. 8. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

II.

On some Occurrences of Ottrelite and Ilmenite Schist in New England.

By J. E. Wolff.

In the series of metamorphosed sediments which, in the many localities, represent nearly every geological horizon, a wide-spread type of rocks are characterized by their fine grain, glistening micaceous aspect, and perfection of cleavage, to which the names of phyllite, micaceous slate, argillaceous mica schist, etc. have been applied. They represent original fine-grained argillaceous sediments, in which the metamorphic development of new minerals combined with the production of cleavage has partially or totally changed the original character. These rocks frequently attract attention by the presence of porphyritic, more or less perfectly shaped crystals, scattered through the fine-grained micaceous paste, which, unlike the analogous crystals of porphyritic eruptive rocks, appear to have formed *later* than the "groundmass." Garnet, biotite, andalusite (chiastolite), staurolite, albite, magnetite, ilmenite, and minerals of the ottrelite group, occur in this way. In this paper some notes are presented on schists or phyllites containing ottrelite or ilmenite plates.

Ottrelite or chloritoid schists of Archean, Cambrian, Carboniferous, and perhaps of later age, have been described from numerous localities in Europe. The Cambrian phyllites of the Ardennes, among which the classical ottrelite schists occur, have undergone a thorough chemical and microscopical investigation by M. Renard.[1] One of these rocks is of particular interest in this connection, namely, the "Phyllade à ilmenite des Forges de la Commune." The bluish gray rock contains numerous small glittering metallic plates which can easily be mistaken for ottrelite; in the section they are transparent on the thin edge, with a brown color,

[1] Bull. Mus. R. Hist. Nat. Belg., Vol I. pp. 212–219. Vol. II pp 127–152, Vol III. pp. 84, 85, 230–268

and are bordered by a fringe of sericite. The optical examination combined with chemical analysis led M. Renard to identify these plates finally as ilmenite. In another rock (Phyllite ottrelitifère de Monthermé) they occur with ottrelite. These metallic plates had been observed elsewhere by M. Renard and others, but their true nature not determined.

Minerals of the ottrelite family ("phyllite," chloritoid, masonite, etc.) have been described from the rocks of New England by various mineralogists, and by T. Sterry Hunt from the palæozoic schists of Canada. The occurrence of this mineral in Maryland, in phyllite, has recently been mentioned by G. H. Williams.[1]

In the complex of gneisses, schists, and massive crystalline rocks which cover the larger part of New England, there are certain areas of partially altered sediments, the palæozoic age of which has been established by fossils or stratigraphic considerations. One of the most important of these is the strip forming the western edge of the Green Mountains, which has been proved by the labors of Dana, Wing, Walcott, and others to belong to the Cambrian and succeeding periods of the Palæozoic. These "Taconic rocks" consist of quartzites, crystalline limestone, phyllites of various kinds, and fine-grained gneisses, with occasional conglomerates, especially near the base. That a large part of the more highly crystalline rocks to the eastward, in Massachusetts at least, represent the same series still further metamorphosed, appears to definitely result from the work of the United States Geological Survey done under the direction of Professor Pumpelly, now going to press.

Another important area of metamorphosed palæozoic sediments occurs in the eastern part of Rhode Island, on the shores of Narragansett Bay, extending northward into Southern Massachusetts; it is of Carboniferous age. The rocks are conglomerates, coal-beds, shales and schists of various kinds, which like the Cambrian rocks of the Green Mountains are intensely crumpled and metamorphosed.

There are two well-known localities for ottrelite in or near this region: one that of the Masonite from Natic, R. I., described by Jackson[2] in garnetiferous mica schist which occurred as glacial boulders, the other that of the ottrelite (Newportite) from the vicinity of Newport, R. I. Mr. T. N. Dale says of this occurrence, "Boulders and pebbles of ottrelite schist abound about Newport, but I have failed to

[1] Johns Hopkins Univ. Circulars, September, 1889.

[2] Geology of Rhode Island, 1840, p. 47.

find any outcrop of it."[1] The carboniferous schists abound in little black metallic plates which resemble ottrelite, so that the rock may have been mistaken for ottrelite schist; but since pebbles of this rock are associated with pebbles of the true ottrelite schist, there is little reason to doubt that the latter occurs in place in the vicinity, and probably of Carboniferous age.[2]

Ottrelite Schist. — The ottrelite schist here described was collected by Mr. Dale, occurring as pebbles on Easton's Beach, Newport. The rock is a silvery-gray, fine-grained mica schist, which has a well marked schistosity (and cleavage), the plane of which bears no relation to the distribution of the ottrelite. This mineral occurs in the well known rhomboid or irregular plates, three or four millimeters in diameter, with brilliant lustre and well marked cleavage surfaces. The latter are pitted with little dull spots, which it is seen in the slide are grains of quartz enclosed by the crystal.

Studied in the thin section, the rock is found to be composed of little rounded grains of quartz. closely interlocking, when not separated by the other constituents, and of minute scales of colorless mica with the optical properties of muscovite, which by their parallel arrangement cause the schistosity of the rock. Certain wavy lines oblique to this structure, which contain less mica and more quartz than the average, may represent the original plane of deposition. A darker variety of the rock contains occasional small plates of chlorite and bands of opaque black substances, which are mixtures of graphite and titaniferous iron ore (ilmenite?) for the powdered rock gives a strong test for titanium and also for graphite.

The ottrelite crystals and somewhat smaller black metallic plates are seen to have no connection with either the plane of schistosity or possible deposition plane. The former mineral occurs in plates of irregular outline, appearing as lathe-shaped cross-sections, frequently twinned several times, with composition parallel to the base, blue and greenish pleochroism, and the other usual optical properties. They are generally filled with little grains of quartz of the same size and shape as those composing the rock outside, which were evidently enclosed by the crystal as it formed; it is noticeable that the muscovite never accom-

[1] A contribution to the Geology of Rhode Island, Am. Journ. Sci., Vol. XXVII. p. 222.

[2] Mr. Dale has found ottrelite schist in place on Conanicut Island, opposite Newport, but the rock has not been examined microscopically. Proceedings of Canadian Institute, 1884–85, p. 21.

panies the quartz in the ottrelite, but buts against the edge of the crystal without altering its character or arrangement in proximity to it. Sometimes the quartz grains fill the interior of the ottrelite in hour-glass shape, but this form has no connection with twinning as in the case figured by Rosenbusch (Mik. Physiog., Vol. I. Plate XXII. Fig. 6), but is evidently a case of crystal growth analogous to the forms so well known in the augites of some eruptive rocks: a skeleton crystal of ottrelite first formed, which did not enclose or else assimilated the quartz, while a later growth, which filled out the double funnel-shaped cavity, was able or obliged to enclose it. In the rock next to be described there are skeleton crystals of ottrelite only partially filled up with the quartz-bearing mineral.

The black plates in this rock are somewhat smaller than those of ottrelite, with a jagged outline. They have sometimes a spindle-shaped cross-section, indicating then that they are discoid, but are generally bounded by straight parallel lines; they are not transparent, but have frequently a yellow leucoxene core, indicating titaniferous iron ore. There is no doubt that they are ilmenite, as determined by M. Renard in the similar rocks of the Ardennes.[1]

These ilmenite plates are generally bordered on both sides by a thin sheet of chlorite, the base of which is parallel to the ilmenite. (The similar ilmenite plates described by M. Renard are bordered by sericite.) The plates are often entirely enclosed in the ottrelite crystals, sometimes one half in, the other half projecting out. The chlorite coating disappears when they are found in the ottrelite, but they are then sometimes bordered by a zone of ottrelite free from quartz inclusions, unlike the rest of the crystal, of the same size and shape as the chlorite, suggesting that the latter was absorbed into the ottrelite when the crystallization took place. Small grains of titanite mixed with black ore are scattered through the rock, and there are occasional prisms of tourmaline.

Ottrelite Graywacke. — This interesting rock was found by Mr. Dale in a glacial boulder at "Paradise," Newport, R. I.

The rock contains fragments of blue and white quartz, enclosed in a dark gray micaceous cement, spangled with small plates of ottrelite.

The slides show that the rock has undergone intense dynamo-metamorphic action; the large fragments of clastic quartz in polarized light exhibit all stages of change from mere straining to breaking and

[1] He mentions the occurrence of these forms in Rhode Island ottrelite schist.

crushing, and at the edges have yielded small broken quartz, which is mingled with the muscovite of the cement. The latter is made up of fragments of detrital quartz, quartz derived from the crushing of the large fragments, and perhaps some quartz formed chemically *in situ*, with muscovite filling the interstices, and even filling the cracks made in the large grains, and therefore evidently of metamorphic origin. There are also larger fragments of quartzite, and rounded aggregates of quartz and muscovite, which represent decomposed clastic feldspar grains.

The ottrelite occurs in this cement in plates of irregular shape, often moulding itself around or enclosing the grains of quartz. It has all the optical properties of the ottrelite described above, and also encloses the quartz grains of the cement, but not the muscovite, and very rarely exhibits the least bending or straining; hence it must have formed after the crushing forces had ceased to act. There are sometimes skeleton crystals of ottrelite, the hollow having the shape of an hour-glass, and transitions to crystals in which the hollow is filled up by ottrelite enclosing quartz. The cement also contains the black metallic plates, small and imperfect, which are sometimes enclosed in the ottrelite.

We may conclude from the microscopic study of these rocks that the ottrelite was the last mineral to form in them: it encloses the grains of quartz of the cement, both when they are easily recognized as clastic in the grauwacke and when of doubtful origin in the fine-grained schist. The muscovite, which is evidently a metamorphic mineral in both rocks, formed before the ottrelite, although not enclosed in it, for in position and arrangement it is not affected by the latter, and it seems necessary to suppose a chemical solution of the muscovite which filled the space between the quartz grains at the time the ottrelite came to fill that space. The ilmenite-chlorite plates also formed before the ottrelite, since they are enclosed in it.

In the grauwacke the muscovite is found penetrating the crushed pebbles of quartz along the cracks, and even penetrating into the substance of the quartz a minute distance where there is no visible break, indicating a marked mobility for the solution from which this mineral formed. The ottrelite, on the other hand, forms in comparatively large unbroken areas enclosing the other minerals, somewhat analogous to a concretionary formation. Such an ottrelite grauwacke illustrates anew the position of ottrelite in the scale of metamorphism, occurring, as it does often, in or associated with rocks that retain at least a part of their original characters. Its late formation in the rock, posterior to quartz, ilmenite, muscovite, etc., may indicate a higher degree of metamorphism than those minerals alone would do, or the presence of some special geological or chemical conditions, to which we have as yet no clue.

Graphite Schist with Ilmenite Plates. — This rock occurs as a boulder on Miantonomah Hill, Newport, R. I., and contains plant impressions (Dale).

It is a soft black graphite schist, containing irregular metallic plates resembling ottrelite, which are two or three millimeters long and 0.12 mm. thick. These plates can easily be split off with a knife, leaving a dull film of chlorite below them. They are imperceptibly magnetic, are attacked with great difficulty by boiling hydrochloric acid, and the yellow solution gives a strong titanium test with tin-foil; they are therefore *ilmenite.* In the slides the rock is composed of small grains of quartz, flakes of muscovite and chlorite, and specks of graphite and iron ore (probably ilmenite). The large ilmenite plates have frequently a spindle-shaped cross-section (i. e. discoid plates), and have a kernel of leucoxene (titanite). Some are bordered on each side by a thin plate of chlorite, some by brilliantly polarizing muscovite. The rock is evidently of Carboniferous age.

Occurrences of minerals of the ottrelite group in the region of schists and gneisses of Central and Western Massachusetts are mentioned in mineralogies, but the writer has found no microscopical descriptions of the rocks. A part of the so called ottrelite schists, such as the "spangled mica-slate" of Hitchcock (Geology of Massachusetts) are probably ilmenite schists.

In the Western or Green Mountain region, ottrelite and ilmenite plates occur in schists or phyllites investigated by the writer for the U. S. Geological Survey, both in specimens collected by Mr. T. N. Dale from the Western Cambrian (or younger) rocks (Taconic region), and also from the Cambrian series of Hoosac Mountain in the axis of the Green Mountains, full descriptions of which will appear in the forthcoming memoir.

The ottrelite schist of Hoosac Mountain occurs in several places in the albite-phyllite series which overlies the basal Cambrian conglomerate. The ottrelite rock is a silvery greenish schist, containing crystals of red garnet and small prisms of tourmaline, and spotted with plates of ottrelite. In the slides the rock is composed of muscovite (sericite) in the usual interwoven aggregates, irregular plates of chlorite, grains of quartz, occasional crystals of albite and the ottrelite, in small irregular plates with the usual pleochroism, etc., which sometimes appear spindle-shaped in cross-section (discoid). Small, irregular black metallic plates also occur in the rock.

The Taconic region of Greylock Mountain, the highest summit in Massachusetts, lies immediately west of the Hoosac series, extending west in turn to the Taconic range, which forms the boundary between New York and Massachusetts. The rocks of this area are in large part phyllites of many varieties and colors, often dotted with crystals of albite like the similar rock of Hoosac Mountain, containing garnets, tourmaline, etc. The black metallic plates are wide-spread in these phyllites, exhibit the same properties, such as very feeble magnetism, difficult solubility in hydrochloric acid, presence of titanium, etc., that those from the Rhode Island graphite schists do; they are therefore *ilmenite.*

In the slides these rocks are composed of sericite, generally intimately interwoven with chlorite, and small grains of quartz. Masses of black ore, prisms of rutile, etc., are abundant. In some varieties the albitic feldspar becomes an essential constituent. The ilmenite plates are commonly sandwiched between two plates of dark green chlorite, exactly as in the Rhode Island rocks. In many of these rocks microscopic plates of ottrelite, spindle-shaped in cross-section, exist enclosed in the meshes of the mica.

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No. 9. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

III.

On Keratophyre from Marblehead Neck, Massachusetts.

By John H. Sears.

This interesting rock formation was first noticed by Prof. W. O. Crosby in the American Naturalist (Vol. XI. No. 10, 1877, p. 585), where he says: "Near the middle of the southwest side of the harbor, visible only at low tide, is a hard, whitish, fine-grained sandstone or arenaceous slate. It overlies unconformably the banded petrosilex found on the shore." In the "Occasional Papers of the Boston Society of Natural History, III. Contributions to the Geology of Eastern Massachusetts," Professor Crosby says again of Marblehead Neck (p. 263): "It is not generally known that this rocky peninsula, which may be regarded as lying on the extreme outskirts of the Boston Basin, includes beds probably referable to the same horizon as the slate and conglomerate on the south and west. Briefly stated the facts are as follows: Near the middle of the northwest shore of the Neck, visible only at low tide, is a hard, whitish, fine-grained sandstone or arenaceous slate; it is evidently largely feldspathic and turns yellowish on weathering. Porphyritically interspersed through the rock are clear, almost transparent, rhomboidal crystals, from one eighth to one fourth of an inch long; these have been examined by Miss Hattie A. Walker and proved to be orthoclase."

The next notice of this rock is in the Proceedings of the Boston Society of Natural History (Vol. XXI. Part 3, p. 288), "On the Trachyte of Marblehead Neck," by Dr. M. E. Wadsworth, in which he says, "Near Boden's Point, on the northwest shore of Marblehead Neck, there is to be seen, exposed between high and low tide, the remains of a trachytic overflow." On page 290, Dr. Wadsworth says: "One of the feldspars, porphyritically enclosed in the groundmass, was obtained in the section. This is clear, glassy, and contains only a slight amount of the groundmass and a few full fluid cavities. It is a simple crystal of sanidin."

Dr. Wadsworth's field-work upon this formation was very thorough, and but little is required in addition to his clear description of it. A few notes, however, taken from his description and the observations of the writer, may be of interest. This formation, now determined to be keratophyre, can be seen at low tide near the residence of Mrs. Harding on Boden's Point, Marblehead Neck. It appears as the much eroded remains of a surface flow, and extends two hundred yards in a northeasterly direction, with a width of sixty feet at the lowest point of observation. There are smaller masses of this rock three hundred yards from this point in the same strike (northeast), which are exposed only at extremely low tides. About five hundred yards south of Boden's Point, near Flying Point, the eruptive granite cuts the metamorphic slate of the Boston Basin series, and near this point also the granite is cut by dikes of quartz-porphyry (felsite). Near the keratophyre, and dipping under it, is a banded felsite. Both the granite and the felsite are cut by diabase dikes. The felsite tends to the northeast, and forms the larger portion of the bed rock of the Neck. The banding of this felsite dips towards the harbor nearly north, and lying upon it is the keratophyre. Between the lowest points of observation and the banded felsite, a conglomerate of varying thickness composed of fine felsitic débris, holding rounded and angular fragments of the felsite, is found in several places enclosed in the keratophyre. In some places the keratophyre rests directly upon the felsite, while in others the conglomerate intervenes between them. The line of contact between the keratophyre and the felsite débris is well marked; specimens of the keratophyre detached at this point show a basal surface very rough and pitted where it conforms to the irregularities of the conglomerate. The keratophyre, being exposed to the sun, rain, and the action of the frost and the ocean waves, is much decomposed on the surface; but the least altered specimens obtained are of a brownish or bluish gray color, having a conchoidal fracture and a compact groundmass, holding, occasionally, large glassy crystals of anorthoclase, some of which are one fourth of an inch in length, and, rarely, plates of biotite. The groundmass in thin section under the microscope is shown to be filled with lath-shaped feldspar crystals, which are somewhat decomposed. The base is an earthy kaolinized mass, with irregular masses of quartz and earthy limonite.

Dr. Wadsworth described the rock from microscopical study as consisting of a groundmass composed of ledge-formed crystals of feldspar,